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THE INTERRELATIONSHIP OF THE NUMBER OF THE TWO TYPES OF VASCULAR BUNDLES IN THE TRANSITION ZONE OF THE AXIS OF PHASEOLUS VULGARIS

J. ARTHUR HARRIS, EDMUND W. SINNOTT, JOHN Y. PENNYPACKER, AND G. B. DURHAM

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INTRODUCTORY

In papers[1] on the anatomy of dimerous[2] and trimerous and of hemitrimerous seedlings we have shown that *Phaseolus vulgaris* is characterized by a structure of the vascular system at the base of the hypocotyl which is rather infrequent in seedling anatomy in general. This is the presence of a variable number of accessory bundles which usually lack protoxylem elements. These are the "Zwischenstränge" of Dodel. We have elsewhere called them intercalary bundles. They may make their appearance in the upper part of the root or in the lower region of the hypocotyl, some rising blindly below and others originating by division of a primary double bundle. These intercalary strands may be distinguished from the other bundles with perfect certainty because of their position and of the absence within them of any protoxylem elements.

In another place[3] we have dealt with the correlations between the number of bundles at different levels in the seedling, that is, the relationship between the vascular system at the base of the hypocotyl and that in the central region of the hypocotyl and epicotyl, and between the bundle system in the hypocotyl and that in the epicotyl. Our present problem is to consider the interrelationships between the two types of bundles present in the hypocotyl just above the region of transition from root to stem structures, and between each of these types and the total number of bundles in this zone.

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[1] Harris, J. Arthur, Sinnott, E. W., Pennypacker, J. Y., and Durham, G. B. The vascular anatomy of dimerous and trimerous seedlings of *Phaseolus vulgaris*. Amer. Jour. Bot. 8: 63–102. 1921. The vascular anatomy of hemitrimerous seedlings of *Phaseolus vulgaris*. Amer. Jour. Bot. 8: 375–381. 1921.

[2] Dimerous seedlings have 2 cotyledons and 2 primordial leaves; trimerous seedlings have 3 cotyledons and 3 primordial leaves; and hemitrimerous seedlings have 3 cotyledons and 2 primary leaves.

[3] Harris, J. Arthur, Sinnott, E. W., Pennypacker, J. Y., and Durham, G. B. Correlations between anatomical characters in the seedling of *Phaseolus vulgaris*. Amer. Jour. Bot. 8: 339–365. 1921.

[The **Journal** for October (8: 375–424) was issued November 14, 1921].

Lack of space precludes the publication of the 30 individual correlation tables upon which the coefficients discussed in this section are based. These may, however, be easily formed from the schedules showing the formula for the basal bundles in other papers of this series.[4]

TABLE 1. *Correlation between Number of Primary Double Bundles and Number of Intercalary Bundles at Base of Hypocotyl*

Line	Trimerous			Dimerous			Difference	$\frac{\text{Diff.}}{E_{\text{diff.}}}$
	N	r	$\frac{r}{E_r}$	N	r	$\frac{r}{E_r}$		
75	142	−.5004±.0424	11.8	142	−.1177±.0558	2.11	−.3827±.0700	5.46
93	155	−.6155±.0337	18.3	155	−.1449±.0530	2.73	−.4706±.0624	7.54
98	183	−.6515±.0286	22.8	183	+.0643±.0496	1.30	−.7158±.0574	12.4
139	106	−.5053±.0488	10.4	305	+.1364±.0379	3.60	−.6417±.0618	6.0
143	221	−.3184±.0408	7.8	420	+.0338±.0329	1.03	−.3522±.0530	5.4

ANALYSIS OF DATA

1. *Relationship between Number of Primary Double Bundles and Number of Intercalary Bundles.* We shall first consider the relationship between the number of primary double bundles and the number of intercalary bundles at the base of the hypocotyl in dimerous and trimerous plants.

The correlation coefficients for the five lines appear in table 1. For the trimerous plants of all five lines the correlations are negative in sign, *i.e.*, the number of intercalary bundles is greater in plants which have a smaller number of primary double bundles, and *vice versa.* For dimerous plants three of the five lines show a slightly negative coefficient, but two show a low positive correlation. The constants indicate that the correlations for the trimerous plants are much higher numerically than those for the dimerous plants. Those for the trimerous are of the order −.3 to −.6 while those for dimerous plants are sensibly zero, averaging + .005. The correlations for the trimerous plants are in all cases several times as large as their probable errors, while those for the dimerous plants could hardly be regarded as statistically significant if only one of the lines were available. The differences, taken with regard to sign, between the correlations for the dimerous and trimerous plants are in each case significant in comparison with their probable errors.

Expressing these results in terms of regression we have the following equations:

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[4] The entries to be selected from the published tables can be determined from the values of N. In lines in which true siblings were available (75, 93, and 98) only siblings have been used, even though additional sections of one or the other type were available. In the two lines in which random samples of seed were used for the production of the dimerous and trimerous seedlings, the largest possible number of individuals available in the tables of the papers cited was employed for the constants here discussed.

	Dimerous	Trimerous
Line 75:	$P = 4.255 - 0.058\,I$	$P = 6.059 - 0.318\,I$
	$I = 1.641 - 0.239\,P$	$I = 4.968 - 0.789\,P$
Line 93:	$P = 4.607 - 0.110\,I$	$P = 5.992 - 0.448\,I$
	$I = 1.398 - 0.127\,P$	$I = 5.200 - 0.846\,P$
Line 98:	$P = 4.099 + 0.035\,I$	$P = 5.984 - 0.392\,I$
	$I = 0.114 + 0.117\,P$	$I = 6.559 - 1.084\,P$
Line 139:	$P = 4.005 + 0.034\,I$	$P = 5.958 - 0.558\,I$
	$I = -2.038 + 0.541\,P$	$I = 2.795 - 0.457\,P$
Line 143:	$P = 4.060 + 0.019\,I$	$P = 5.924 - 0.408\,I$
	$I = 0.047 + 0.059\,P$	$I = 1.732 - 0.249\,P$

The mean number of intercalary bundles associated with given numbers of primary double bundles and the theoretical means as given by the regression straight lines are shown on diagram 1.

For the normal plants of lines 75, 93, and 139 the agreement between the observed means and the regression line is very satisfactory. In line 98 a single seedling with 8 primary double bundles and 4 intercalary bundles gives a positive sign to the correlation and makes the agreement of theoretical and empirical means very poor indeed. In lines 139 and 143 the correlation is also positive. It must be noted that we are dealing here with a very narrow range of both primary double bundles and intercalary bundles, and with very small frequencies in some of the classes.

For the abnormal plants the agreement of empirical means and theoretical lines is apparently very poor indeed. This is perhaps largely attributable to two facts:

(*a*) The frequencies of primary double bundles are, practically speaking, concentrated in two classes, 5 and 6 bundles. From 93 to 99 percent of the seedlings fall in these two classes. As a result of this condition, the obtaining of trustworthy averages for the extreme classes of primary double bundles is, practically speaking, impossible.

(*b*) The influence of the two principal classes (5 and 6) of primary double bundles is such as to throw the theoretical mean number of intercalary bundles for higher classes of primary double bundles on the negative side of 0 in four of the five cases.

As a consequence, the actual mean number of intercalary bundles must lie above the line in all cases in which more than 6 primary double bundles are formed.

Whether these irregularities represent a significant deviation from linearity can be determined only when far larger series of data are available.

While the primary double bundles must probably be regarded as more fundamental structures than the intercalary bundles, it seems of interest to determine the mean number of primary double bundles associated with each number of intercalary bundles.

The lines for the regression of number of primary double bundles on number of intercalary bundles are represented with the empirical means on diagram 2. These figures show that, with the exception of the normal plants of lines 98, 139, and 143, the number of primary double bundles decreases slightly as the number of intercalary bundles increases. The rate of decrease is somewhat greater in the abnormal than in the normal plants.

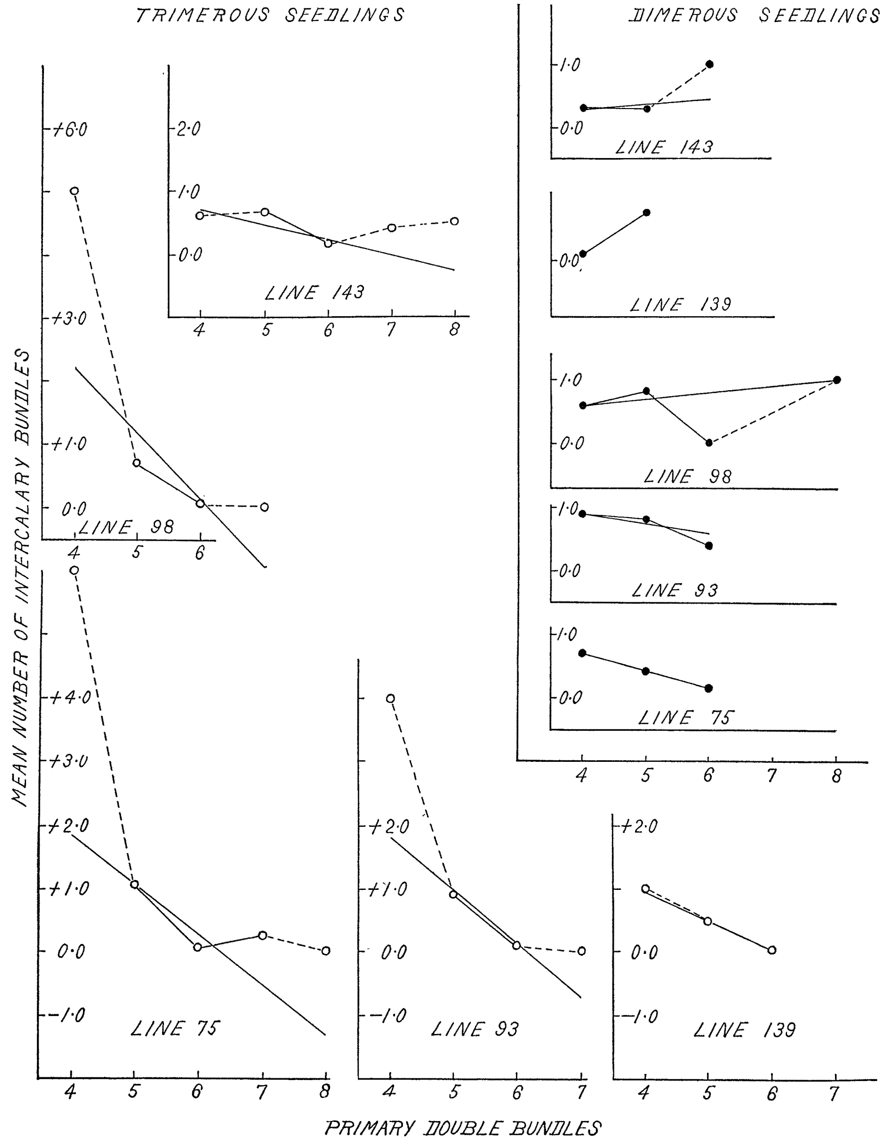

DIAGRAM 1. Regression of number of intercalary bundles on number of primary double bundles, at base of hypocotyl.

It is suggestive to note that the negative correlation between number of primary double bundles and number of intercalary bundles demonstrated here within seedlings of one class with regard to external structure is also evident when we pass from a type of seedling with a smaller to one with a higher number of primary double bundles. It has been shown in an earlier paper that (*a*) the number of trimerous seedlings having intercalary bundles is generally smaller than the number of dimerous seedlings with these accessory structures, and that (*b*) the average number of intercalary bundles is generally smaller in trimerous than in dimerous seedlings.

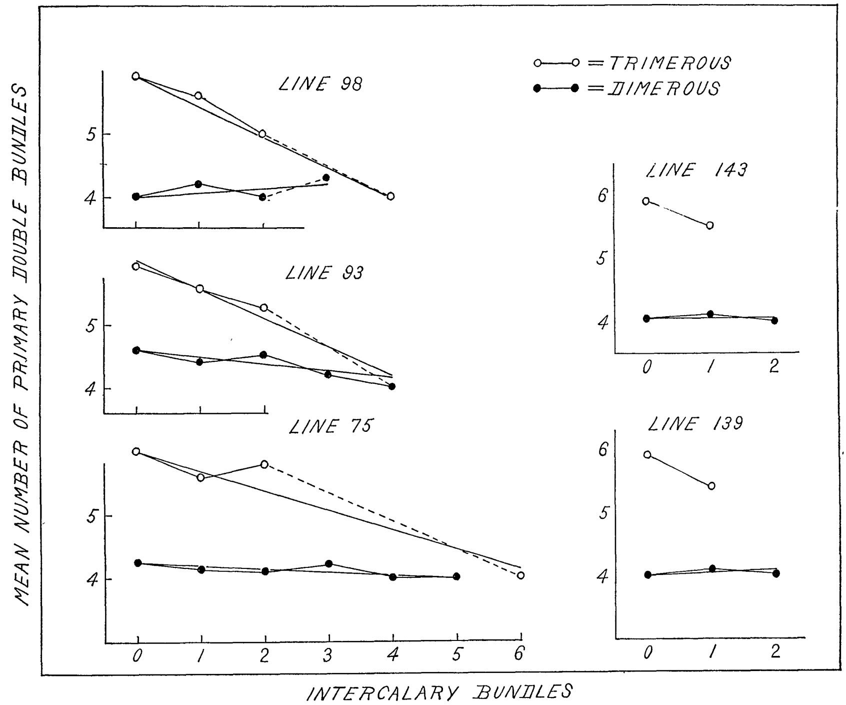

DIAGRAM 2. Regression of number of primary double bundles on number of intercalary bundles, at base of hypocotyl.

2. *Relationship between the Total Number of Bundles and the Number of Bundles of the Two Types.* We may now inquire to what extent the variation in the total number of bundles depends upon the primary double bundles and to what extent upon the number of intercalary bundles. As a first step we determine the correlation between the total number of bundles and the number of primary double bundles, and between the total number of bundles and the number of intercalary bundles. These results are set forth in table 2.

We note that the correlations between the total number of bundles and the number of intercalary bundles are in all cases high, ranging from +.42

to +.80 in the trimerous and from +.76 to +.97 in the dimerous plants. The correlations for the dimerous plants are in all five cases slightly higher than those for the trimerous plants.

TABLE 2. *Comparison of Correlation between Total Bundles and Primary Double Bundles,* r_{bp}*, and between Total Bundles and Intercalary Bundles,* r_{bi}*, at Base of Hypocotyl*

	Trimerous			Dimerous			Difference	$\frac{\text{Diff.}}{E_{\text{diff.}}}$
	N	r	$\frac{r}{E_r}$	N	r	$\frac{r}{E_r}$		
Line 75								
r_{bi}	142	+.7788±.0222	35.1	142	+.8872±.0120	73.9	−.1084±.0245	4.42
r_{bp}	142	+.1532±.0552	2.77	142	+.3536±.0495	7.14	−.2004±.0741	2.70
$r_{bi}-r_{bp}$.		+.6256±.0591	10.6		+.5336±.0510	10.5		
Line 93								
r_{bi}	155	+.6934±.0281	24.7	155	+.7628±.0226	33.8	−.0694±.0361	1.92
r_{bp}	155	+.1409±.0531	2.65	155	+.5292±.0390	13.6	−.3883±.0655	5.92
$r_{bi}-r_{bp}$.		+.5525±.0600	9.21		+.2336±.0447	5.23		
Line 98								
r_{bi}	183	+.8001±.0179	44.6	183	+.8833±.0109	81.0	−.0832±.0200	4.16
r_{bp}	183	−.0664±.0496	1.34	183	+.5245±.0361	14.5	−.5909±.0616	9.59
$r_{bi}-r_{bp}$.		+.8665±.0529	16.4		+.3588±.0374	9.59		
Line 139								
r_{bi}	106	+.4203±.0539	7.79	305	+.9721±.0021	457.4	−.5518±.0539	10.2
r_{bp}	106	+.5707±.0422	12.9	305	+.3649±.0335	10.9	+.2058±.0555	3.71
$r_{bi}-r_{bp}$.		−.1504±.0697	2.16		+.6072±.0336	18.1		
Line 143								
r_{bi}	221	+.4382±.0367	11.9	420	+.8715±.0079	110.2	−.4333±.0375	11.55
r_{bp}	221	+.7126±.0223	31.9	420	+.5196±.0240	21.6	+.1930±.0328	5.88
$r_{bi}-r_{bp}$.		−.2744±.0429	6.40		+.3519±.0253	13.9		

The correlation between the total number of bundles and the number of primary double bundles is in general much lower. In line 98 the coefficient actually has the negative sign in the trimerous series. The differences between the correlation coefficients for total bundles and intercalary bundles, and for total bundles and primary double bundles, range from −.27 to +.87 in the trimerous plants and from +.23 to +.61 in the dimerous plants.

It is clear that the two types of plants differ rather fundamentally in this correlation. The correlation between the total bundles and the primary double bundles is very low in the trimerous plants. It is a much more substantial value in the dimerous plants.

Pursuing this point one step farther, we may determine by a special formula the relationship between the total number of bundles and the deviation of the number of intercalary bundles from the number which would be expected if the number of primary double bundles and intercalary bundles were in proportion to the total number of bundles formed.

Determining the correlation between the total number of bundles, b, and the deviation of the number of intercalary bundles, i, from their probable value by the formula[5]

$$r_{bz} = \frac{r_{bi} - r_b/r_i}{\sqrt{1 - r_{bi}^2 + (r_{bi} - r_b/r_i)^2}}$$

$$\text{where } z = i - \frac{\bar{i}}{\bar{b}} b,$$

we have the values given in table 3.

TABLE 3. *Correlation between Total Bundles at Base of Hypocotyl and Deviation of Number of Intercalary Bundles from Their Probable Number*

Line	Trimerous			Dimerous			Difference	$\frac{\text{Diff.}}{E_{\text{diff.}}}$
	N	r	$\frac{r}{E_r}$	N	r	$\frac{r}{E_r}$		
75	142	.7643±.0235	32.5	142	.8513±.0156	54.6	−.0870±.0283	3.07
93	155	.6787±.0292	23.2	155	.6693±.0299	22.4	+.0094±.0412	0.22
98	183	.7944±.0184	43.2	183	.8433±.0144	58.6	−.0489±.0224	2.18
139	106	.4066±.0546	7.45	305	.9701±.0023	421.8	−.5636±0.546	10.3
143	221	.3841±.0386	9.95	420	.8510±.0090	94.6	−.4669±03.96	11.8

The coefficients are positive and high, and very consistent for the two types of seedlings. They show that within one morphological type of seedling[6] an increase in the total number of bundles is primarily due to the formation of intercalary bundles, rather than to variation in the number of primary double bundles, although both types of bundles contribute to the end result.

SUMMARY

An investigation of the interrelationship of the numbers of primary double bundles, intercalary bundles, and total bundles (primary double bundles plus intercalary bundles) at the base of the hypocotyl in dimerous and trimerous seedlings of *Phaseolus vulgaris* leads to the following results:

1. In the trimerous seedlings there is a negative correlation of about medium value ($r = -.5 \pm$) between the number of primary double bundles and the number of intercalary bundles. Thus the number of intercalary bundles is smaller in seedlings with larger numbers of primary double bundles and *vice versa*. In dimerous seedlings the correlation is perhaps also negative in sign, but practically zero numerically.

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[5] Harris, J. Arthur. The correlation between a variable and the deviation of a dependent variable from its probable value. Biometrika 6: 438–443. 1909; also, Further illustrations of the applicability of a coefficient measuring the correlation between a variable and the deviation of a dependent variable from its probable value. Genetics 3: 328–352. 1918.

[6] The differentiation of trimerous and dimerous seedlings has been shown to be due primarily to an increase in the number of primary double bundles.

This result for seedlings of the same morphological type is suggestive in its relation to the results of a comparison of seedlings which are externally dimerous and trimerous, since in general trimerous seedlings show an increase in number of primary double bundles but a decrease in number of intercalary bundles as compared with dimerous seedlings. As a result of this numerical compensation, most conspicuously evident in the trimerous seedlings, the total number of bundles shows a lower variability than it would if the numbers of the two types of bundles were quite independent.

2. The correlation between the total number of bundles (primary double bundles plus intercalary bundles) and the number of intercalary bundles is high. The coefficients for the dimerous seedlings are somewhat higher than those for the trimerous seedlings. The correlation between the total number of bundles and the number of primary double bundles is generally much lower. The correlation between the total number of bundles and the deviation of the number of intercalary bundles from that which would be expected if they occurred in the same proportionate frequency throughout the entire range of total bundle number is positive in sign and substantial in magnitude. In both types of seedlings variation in the number of intercalary bundles is therefore an important factor in determining variation in the total number of bundles at the base of the hypocotyl.